Data Structures, Algorithms, and their Applications within Computer Systems (CS 5008)

Graduate Course, Khoury College of Computer Sciences
Northeastern University, Vancouver Campus
Spring 2021 Semester

We acknowledge that the land on which we gather is the unceded territory of the Coast Salish Peoples, including the territories of the xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh (Squamish), and səlilwətaɬ (Tsleil-Waututh) Nations.

Class Hours:	Thursday 1:00PM-3:00PM (Pacific time)
Class Location:	Northeastern Vancouver Campus (333 Seymour), Room 901C
Instructor:	Yvonne Coady (m.coady@northeastern.edu) Richard Hoshino (r.hoshino@northeastern.edu)
Teaching Assistants	To be confirmed
Textbooks	(recommended) Grokking Algorithms (recommended) The Algorithm Design Manual (recommended) Computer Systems: A Programmer's Perspective (recommended) The C Programming Language

CS 5008 presents an integrated approach to the study of data structures, algorithms, and their application within systems topics. We introduce a variety of fundamental algorithmic techniques (divide-and-conquer, dynamic programming, graph algorithms) and systems topics (models of computation, computer architecture, compilation, system software, networking). The integration of topics is demonstrated through programming assignments in the C language that implement fundamental data structures (lists, queues, trees, maps, graphs) and algorithms as they are applied in computer systems. Additional breadth topics include programming applications that expose students to primitives of different subsystems using threads and sockets.

NOTE: in addition to our class time every Thursday (1:00PM-3:00PM), all students are automatically enrolled in CS 5009, the recitation course for CS 5008. This recitation will take place every Tuesday (1:00PM-3:00PM), and will be led by the instructor who taught CS 5008 on the previous Thursday. Attendance is expected.

The Tuesday recitation will serve two purposes: (i) to further deepen your understanding of the topics covered in class on the previous Thursday, and (ii) having dedicated class time for you to ask any questions you have on the weekly assessment that will be due the following day.

Course Objectives

This bridge course is open to all students in the Align MSCS Program, and will contribute to your ability to achieve the MSCS program objectives, which are:

1. Exhibit proficiency in the design, implementation, and testing of software.
2. Demonstrate skills and experience working in small teams.
3. Apply algorithmic and theoretical computer science principles to solve computing problems from a variety of application areas.
4. Demonstrate the ability to learn and develop competencies in specialized or emerging computer science fields.

Here are the specific Learning Outcomes for CS 5008.

Systems content

1. Explain the basic terminology of computing systems, various models of computation (e.g., sequential, multithreaded, parallel), and the role of the operating system as a resource manager for executing processes.
2. Analyze assembly code and its relationship to C code, the fetch/execute cycle, and basic system architecture
3. Explain the basic terminology and architecture of networks and implement basic programs that include socket programming.
4. Gain experience with common systems programs including compilers, linkers, and debuggers.

Algorithms content

1. Implement common data structures (lists, stacks, queues, trees, maps, graphs) and explain the implications of data structure choice on program efficiency.
2. Analyze the computation and storage complexity of algorithms by employing the substitution method, the Master method, and recursion trees.
3. Explain the designs of, and tradeoffs between, different algorithmic approaches to a problem (e.g., searching, sorting, scheduling).
4. Explain proofs related to algorithm correctness and write a simple proof using loop invariants.
5. Implement programs using the C language.

Integration

Explain how to choose appropriate data structures and algorithms based on problem definition, input data size, and performance characteristics of underlying computer systems.

Course Overview

Our course will consist of thirteen modules. The first seven modules will be led by Yvonne Coady, and the last six modules will be led by Richard Hoshino.

First Half: Data Structures and their Application within Computer Systems

- Overview of Computer Systems and Linux "Crash" course!
- The C Programming Language: Building Blocks and Data Structures
- Debugging: A peek into Assembly, CPU Architecture and Operating Systems
- Writing Bigger Software: Compilers, Linkers, and Code Generation
- Processes and the Memory Hierarchy
- Concurrency
- Networking

Second Half: Algorithms and their Application within Computer Systems

- Quadratic Sorting (Selection, Insertion, Bubble) and Intro to Analysis of Algorithms
- Primer on Proofs, and Analysis of O(n log n) Sorting (Merge Sort, Quick Sort)
- Algorithm analysis on trees and heaps.
- Graph Algorithms
- Greedy Algorithms
- Dynamic Programming

Course Schedule

Week	Work Due (by Wednesday 1PM)	% of Grade	Date of Class	Topic in Class
1	-	-	Thursday, January 21	*Systems and Linux*
2	**Homework 1**	**5%**	Thursday, January 28	*Programming in C*
3	**Homework 2**	**5%**	Thursday, February 4	*Debugging and Assembly*
4	**Homework 3**	**5%**	Thursday, February 11	*Bigger Systems!*
5	**Homework 4**	**5%**	Thursday, February 18	*Processes and Memory*
6	**Homework 5**	**5%**	Thursday, February 25	*Concurrency*
7	**Homework 6**	**5%**	Thursday, March 4	*Networking*
8	**Course Synthesis 1**	**10%**	Thursday, March 11	*Selection, Insertion, Bubble Sort*
9	**Problem Set 1**	**7%**	Thursday, March 18	*Primer on Proofs, Analysis of Sorting*
10	**Problem Set 2**	**7%**	Thursday, March 25	*Trees, Heaps, Heap Sort*
11	**Problem Set 3**	**7%**	Thursday, April 1	*Graph Algorithms*
12	**Problem Set 4**	**7%**	Thursday, April 8	*Greedy Algorithms*
13	**Final Project Proposal**	**0%**	Thursday, April 15	*Dynamic Programming*
14	**Course Synthesis 2**	**10%**	Thursday, April 22	*Final Project Work*
15	**Final Project Report**	**10%**	Thursday, April 29	*Final Project Presentations*

The above percentages add up to 88%. The remaining 12% comes from weekly in-class quizzes (10%) and personal SAIL reflections (2%), both of which are explained on the next page.

Course Assessment

There are six methods of assessment in this course.

- **6 Homework/Labs (30%)** consist of programming assignments that will enable you to implement fundamental data structures (lists, queues, trees, maps, graphs) to solve various problems. In addition to learning how these data structures work, these assignments will develop your skills in designing, implementing, and testing programs in the C programming language.

- **4 Problem Sets (28%)** consist of five multi-part questions that are based on key concepts and ideas that are uncovered during class. The first three questions are to be done individually, while the last two questions are to be done in pre-assigned teams of three.

- **10 In-Class Quizzes (10%)** take place at the beginning of each class, based on the weekly course readings that you are to complete in preparation for that class. Half of the grade will be based on your individual responses, while the other half will be based on group responses to the same questions in your pre-assigned teams. There will be more than ten quizzes in this course, but only your top ten will count towards your final grade.

- **2 Course Syntheses (20%)** consist of short answer questions, as well as several multi-part problems connecting different areas of the course, allowing you to synthesize what you have learned. Think of the Course Synthesis as a week-long individual take-home exam where you may consult your class notes but not your classmates or any online resources other than the ones that are explicitly permitted by the course instructor.

- **4 SAIL Reflections (2%)** are your personal reflections on your journey of self-authored integrated learning (SAIL) in this course. You will reflect on your growth across five learning dimensions: Intellectual Agility, Global Mindset, Social Consciousness and Commitment, Professional and Personal Effectiveness, and Well-Being. For more details, check out https://sail.northeastern.edu/about/.

- **1 Final Project (10%)** work occurs during the last two weeks of the course, in lieu of a final examination. Each group will select a topic on any area of CS 5008 whose concepts we will uncover in this course. Your group will submit a project proposal, a written report, and also deliver a presentation on the last day of the course.

We will use the following scale to convert numerical scores into letter grades:

A	93.00% – 100.00%
A-	90.00% – 92.99%
B+	86.00% – 89.99%
B	82.00% – 85.99%
B-	77.00% – 81.99%
C+	73.00% – 76.99%
C	69.00% – 72.99%
C-	65.00% – 68.99%
F	Less than 65.00%

Course Pedagogy

Our time in the classroom (virtual or otherwise!) will be devoted to Team Based Learning activities. In Computer Science, we seldom get anything right on the first try. We see how an attempt turned out, and we try again. Often, any solution to a problem has a series of trade-offs, all of which must be considered! Our classroom activities will reflect this approach as well; so please be prepared to present and discuss your solutions, even if you're not sure that your answer is "right"!

When you come to class, we ask that you be fully present. No phones are permitted in the classroom. If you use a laptop, use it only to take notes. Please be respectful of your fellow students and instructors by participating attentively and non-disruptively.

To create and preserve a classroom atmosphere that optimizes teaching and learning, all participants share a responsibility in creating a civil and non-disruptive forum for the discussion of ideas. Students are expected to conduct themselves at all times in a manner that does not disrupt teaching or learning. Your comments to others should be constructive and free from harassing statements.

In order for this course to be a meaningful learning experience, you will need to come to each class well-prepared, with all assigned readings and videos complete, as well as your individual work finished to the best of your ability. This emphasis on pre-class work is the reason why our class meets for only 2 hours each week. If you do not complete the pre-class work, you will have a hard time following the in-class activities, which will make it that much harder for you to successfully complete the course. Please be prepared to spend a <u>minimum</u> of 20-25 hours per week on this course!

Course Forum

We have a Canvas page, on which we will post all assessments, class materials, pre-class readings, pre-class videos, and grades. Please bookmark this page as you will check it regularly:

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https://northeastern.instructure.com/courses/76714

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<u>Textbook</u>: Students are not required to purchase a textbook for this course. At least one recommended textbook is provided on Canvas. Students are encouraged to use these resources. While these are not the only resources available on the web, these are the ones that we have identified as being most useful to students. We also encourage students to share resources that they find useful so that we can (if appropriate) add them to this list.

<u>Course Discussions</u>: Canvas will be used for class discussion and course announcements. It also provides students with a platform for getting you help fast and efficiently from classmates, the TAs, and the instructor. Rather than emailing questions to the teaching staff, we encourage you to post your questions on Canvas.

<u>C</u>: This class will be using the C programming language. For more information on C, visit https://www.learn-c.org/

Course Policies

Accommodations

The goal is for every student to succeed in this course. If you require any accommodations (e.g. child care during class hours, extra time to complete assignments, support for a disability), let us know immediately so that we can work out appropriate arrangements. Speak to your instructor(s) at the end of class or contact one of us by email, and we will set up a time to meet during the first week of the course. We look forward to learning how we can be of service to you.

Attendance and Participation

It is expected that you attend every class and participate. We begin each day at 1:00PM sharp. If you must miss a class for any reason (e.g., illness, family emergency, religious observance), contact your instructor by email. Regardless of the reason, it is your responsibility to catch up on the material you have missed, and obtain the notes from a classmate (not from us).

Students who are absent repeatedly from class will be evaluated by faculty responsible for the course to ascertain their ability to achieve the course objectives and to continue in the course.

Assessments

With the exception of the In-Class Quizzes and Final Project, all assessments are due at **1PM** on Wednesday: one day before the start of class. The course assessments are purposely due 24 hours before class, so that you have time on Wednesday afternoon and Thursday morning to complete all of the readings in preparation for the class.

Late Penalties

Any assessment that is late will be subject to a 50% penalty. You are allowed *one* exception to this policy, where you are allowed a reasonable extension to any assessment, with no penalty, provided you have a doctor's note or some other compelling reason. Additional exceptions will only be given under extenuating circumstances. Note that the Late Penalty only applies to Homework/Labs, Problem Sets, and Course Syntheses. The remaining assessments (In-Class Quizzes, SAIL Reflections, Final Project) must be submitted on time; failure to do so will result in an automatic zero.

Scheduling Meetings

At any time during the course, if you have any concerns, contact us by email, and we will set up a one-on-one meeting at a mutually convenient time. Please do NOT message us on Microsoft Teams. Contact us via email: m.coady@northeastern.edu and/or r.hoshino@northeastern.edu.

If you need hints on the assessments, please wait until our Tuesday recitations. For all other questions/concerns/issues, let's meet individually.

Technology

As part of our commitment to supporting students, NUFlex gives students the option of attending class on campus or attending remotely via video-conference. For each of our 15 recitations and 15 classes, you may attend in person or attend remotely: the choice is yours.

For those of you attending the class remotely, we will use Zoom (www.zoom.us). The login details are as follows:

https://northeastern.zoom.us/j/95891335423
(Meeting ID: 958 9133 5423, no password)

Students joining via Zoom will adhere to the same rules and expectations as those attending in person: being present, actively engaging in discussions, asking questions, and participating in group activities. Because you will be working in teams where some of your team members will be on campus while others will be joining remotely, we ask all students to be _fully present_ during the class and ensure a healthy learning environment.

This requires that students in the classroom refrain from using their phones and keep them out of sight, and refrain from browsing non-course related topics. Students joining remotely will ensure that any distractions in their near surroundings are eliminated, or at least minimized to the best of their ability. Please create a distraction-free learning environment to optimize your learning.

For those of you joining via Zoom, we would very much appreciate it if you could leave your video camera ON for the entire class. This enables us to see you all on my screen, so that we can better gauge the reactions of the class, appropriately pace the class, and more quickly respond to any questions you have. (If you prefer to leave your video camera OFF, especially for reasons of personal safety and comfort, then we will fully understand.)

Classroom Conduct

To create and preserve a classroom atmosphere that optimizes teaching and learning, all participants share a responsibility in creating a civil and non-disruptive forum for the discussion of ideas. Students are expected to conduct themselves at all times in a manner that does not disrupt teaching or learning.

Your comments to others must be constructive and free from harassing statements. You are encouraged to disagree with other students and the instructor, but such disagreements need to respectful and be based upon facts and documentation, rather than prejudices and personalities. The instructor reserves the right to interrupt conversations that deviate from these expectations.

Repeated unprofessional or disrespectful conduct may result in a lower grade or more severe consequences.

Title IX Policy

Title IX of the USA Education Amendments of 1972 protects individuals from sex or gender-based discrimination, including discrimination based on gender-identity, in educational programs and activities that receive federal financial assistance. Though our campus is located in Canada, all Northeastern University campuses follow the Title IX Policy.

Northeastern's Title IX Policy prohibits Prohibited Offenses, which are defined as sexual harassment, sexual assault, relationship or domestic violence, and stalking. The Title IX Policy applies to the entire community, including male, female, transgender students, faculty and staff.

If you or someone you know has been a survivor of a Prohibited Offense, confidential support and guidance can be found through University Health and Counseling Services staff and the Center for Spiritual Dialogue and Service clergy members. By law, those employees are not required to report allegations of sex or gender-based discrimination to the University.

Alleged violations can be reported non-confidentially to the Title IX Coordinator within The Office for Gender Equity and Compliance at: titleix@northeastern.edu and/or through NUPD Emergency 617.373.3333; Non-Emergency 617.373.2121. Reporting Prohibited Offenses to NUPD does NOT commit the victim/affected party to future legal action.

Faculty members are considered "responsible employees" at Northeastern University, meaning they are required to report all allegations of sex or gender-based discrimination to the Title IX Coordinator.

In case of an emergency, please call 911. Please visit http://www.northeastern.edu/titleix for a complete list of reporting options and resources, both on-campus and off-campus.

Collaboration and Academic Honesty

Computer science, both academically and professionally, is a collaborative discipline. In any collaboration, however, all parties are expected to make their own contributions and to generously credit the contributions of others. In our class, therefore, collaboration on assessments is encouraged, but you as an individual are responsible for understanding all the material in the assignment and doing your own work. Always strive to do your best, give generous credit to others, start early, and seek help early from both you professors and classmates.

The following rules are intended to help you get the most out of your education and to clarify the line between honest and dishonest work. The professor reserves the right to ask you to verbally explain the reasoning behind any answer or code that you turn in and to modify your project grade based on your answers. It is vitally important that you turn in work that is your own.

If you have had a substantive discussion of any assessment (Homework/Lab, Problem Set) with a classmate, then be sure to cite them in your report. If you are unsure of what constitutes "substantive", then ask us or err on the side of caution. You will not be penalized for working together. You must not copy answers or code from another student either by hand or electronically. Another way to think about it is that you should be talking English with one another, not C. The following rules apply to anything you hand in for a grade.

- You may not copy anyone else's code or solution under any circumstances. This includes online sources.
- You may not permit any other student to see any part of your program or solution.
- You may not permit yourself to see any part of another student's program or solution.
- You may not post a public question to Canvas that contains any part of your code.
- You may consult online resources as part of your course work, but you may not copy code or solutions from online sources. If you get an idea of how to solve a programming problem from an online source, include a short citation in a code block at the top of your C file.

As with all other courses at Northeastern, you are expected to adhere to the university's academic integrity policy (http://www.northeastern.edu/osccr/academic-integrity).

If you are unsure about the plagiarism policy, **please ask us!**

Feedback

Your opinions are very important to us. All students are strongly encouraged to use the Teacher Rating and Course Evaluation (TRACE) system, at https://www.northeastern.edu/trace/, to complete your course evaluations. A reminder about TRACE should arrive via email about two weeks before the end of the course.

In addition, we will be asking for your feedback at least once, about halfway through the semester. However, if you have concerns about the course, do not wait until you are asked. Please schedule a meeting with us, and we will discuss your concerns then.

Thank you for taking this course, and entrusting us to shape your education here at Northeastern. We are so excited to serve as your instructors for CS 5008!